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Advances in Particle Sampling and Measurement

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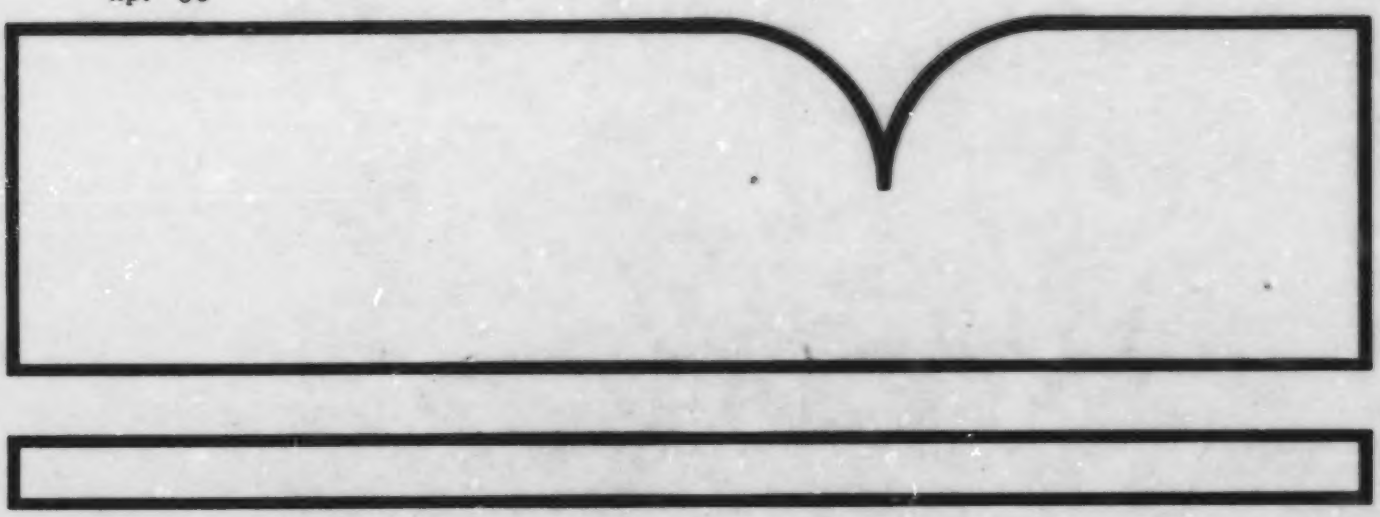

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16. ABSTRACT The paper, by five authorities who contributed significantly to the second symposium on advances in particle sampling and measurement (October 1979 in Daytona Beach, FL) summarizes salient developments in the field. Current techniques were described as being expensive, complicated, and less accurate than desirable. Significant improvements would result in such benefits as: (1) better understanding and quantification of control device behavior (which could expedite the evolution of more efficient control devices); (2) more accurate assessment of environmental and health effects related to various pollution sources; and (3) use of particulate emission measurements as forms of process monitors. In addition to new developments, there was also considerable interest in inhalable particles (airborne particles with aerodynamic diameters of 15 micrometers or less) since new particulate air-quality standards based on inhalable particles are likely to be established by the EPA. Discussed during the symposium were: impactors (including virtual impactors), aerodynamic particle size analyzers, sample collection and dilution, real-time monitors and data reduction, and prototype instruments.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Aerodynamics	Pollution Control	13B	20D
Particles	Data Reduction	Stationary Sources	14G	09B
Dust	Piezoelectricity	Inhalable Particles	11G	20C
Aerosols	Kinetics	Isokinetics	07D	20K
Sampling			14B	
Measurement				
Impactors			13I	

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Advances in particle sampling and measurement

Five authorities, who significantly contributed to the second symposium on this subject, summarize the salient developments

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"At the present time, particle sampling and measurement techniques are expensive, complicated, and less accurate than is desirable. If the technology of particle sampling is improved significantly, possible benefits would include:

- a better understanding and quantification of control device behavior, which in turn could expedite the evolution of more efficient control devices
- more accurate assessment of environmental and health effects related to various pollution sources
- the use of particulate emission measurements as forms of process monitors."

The above remark by A. B. Craig of the Environmental Protection Agency (director, Industrial Processes Division, Industrial Environment Research Laboratory) at the opening of this symposium underscores the importance of particle sampling and measurement and the reason for the continued interest in the subject. The symposium was held in Daytona Beach, Fla., Oct. 8-10, 1979, following an earlier symposium in Asheville, N.C., in May 1978, (*ES&T*, August 1978, p 881). Approximately 130 people attended this year's meeting. Southern Research Institute (Birmingham, Ala.) organized the symposium; D. Bruce Harris of EPA was the chairman.

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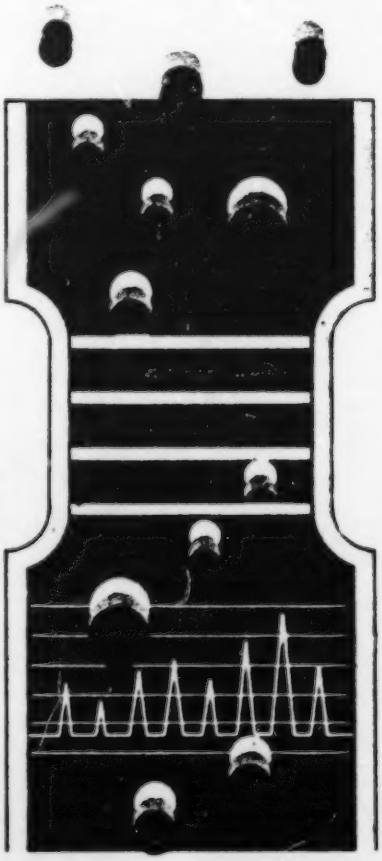


Unlike last year's symposium, which reviewed the state of the art of particle sampling and measurement and also reported on new developments, this year's meeting was devoted mainly to new developments. There was also considerable interest in the subject of "inhalable particles," since new particulate air-quality standards based on inhalable particles are likely to be established by EPA. Inhalable particles are defined by EPA as airborne particles with aerodynamic diameters of 15 μm or less.

Using proper words

The first session began with a plea from the session chairman, Otto Raabe, to use the terms "particle," "aerosol," and "particulate" in a scientifically and grammatically correct way. "Particle" means a microscopic bit of matter which can be either solid or liquid. "Aerosol" is defined as a system of particles suspended in a gas. The gas is usually, but not necessarily, air.

Finally, "particulate" is commonly an *adjective* meaning "of, pertaining to, or composed of individual particles" (Random House "Dictionary of the English Language," Random House, N.Y.). Thus "particulate matter" is scientifically and grammatically correct, whereas "particulates" is best avoided since a perfectly good word, "particles," is available.

Impactors, virtual impactors

Several papers dealt with the subject of impactors and virtual impactors. Thomas Yule, a physicist from Argonne National Laboratory, presented a paper entitled "An Experimental Study of Virtual Impactors." He reviewed the principle of operation of the virtual impactor that aerodynamically separates particles by accelerating them through a nozzle towards a semistagnant (low minor-flow rate) collection inlet, with the main aerosol flow diverted at right angles so that the larger particles are carried by their forward momentum into the minor flow. The main flow is depleted of larger particles, while the minor flow contains primarily the larger particles.

Dr. Yule discussed the history of the development of these devices, from the British cascade centripeter of 15 years ago to several generations of so-called dichotomous virtual impactors. In the course of his work with alpha-emitting radioactive aerosols, he designed a virtual impactor sampling system and experimentally tested its performance.

For these tests, monodisperse aerosols of dioctylphthalate (DOP) produced with an ultrasonic vibrating stream droplet generator and polystyrene latex were used. He varied the different parameters and measured the changes in performance. The parameters varied included:

- the acceleration nozzle-to-collection probe distance
- the ratio of the collection probe-to-nozzle diameters
- the ratio of collection probe-to-inlet flows.

Measurements were also made with different collection probe geometries.

The data were applied to a dimensional analysis to provide general relationships using the Stokes numbers for the particles and a calculated effective minor-flow collection efficiency. This provided a predictive model that could be used to estimate the performance of the virtual impactor from the operating conditions.

Yule emphasized the importance of particle losses under some operating conditions and the importance of selecting operating conditions that are suited to the planned applications.

The second speaker was Virgil Marple of the University of Minnesota, whose paper was "Theoretical Studies of Virtual Impactors." Dr. Marple, who is well-known for his classic theoretical study of conventional impactors, has applied similar methods to describing the behavior of virtual impactors. The Navier-Stokes equations were numerically evaluated, along with the equations of particle motion, to calculate the expected collection characteristics and wall losses. A system of dimensionless parameters was mathematically defined, based upon the principles of dimensional and dynamic similarity.

The effects that were studied included those associated with nozzle Reynolds number (1–15 000), the fraction of flow passing through the collection probe (5–25%), the collection probe diameter (1.16–1.49 times the nozzle diameter), the nozzle throat length (0.013–2.5 times the nozzle diameter), and the nozzle-to-collection-probe distance (0.25–2 times the nozzle diameter). Both large and small particles were modeled.

Marple found that the aerosol passing through a virtual impactor can be resolved into three regions:

- particles passing the collector in the small particle flow stream
- larger particles passing with the minor flow stream into the collector
- losses at the inner surface of the collector.

The results show that most parameters, with the exception of the nozzle flow Reynolds number, have little effect on the large particle collection efficiency. However, the effect on the small particle collection efficiency and collection probe losses are significant for many of these parameters.

The third speaker was Dale A. Lundgren of the University of Florida, who presented a paper coauthored by Michael L. Smith entitled, "An Impactor for Heavy Grain Loading." This paper discussed the commercially available Andersen Model HCSS sampler (Andersen Samplers, Inc., Atlanta, Ga.), which was specifically designed for sampling aerosols at concentrations up to several grams per cubic meter.

Conventional impactors would quickly overload and malfunction under these conditions. The HCSS consists of two impaction chambers in series, followed by a cyclone separator, and backup filter thimble. Construction of stainless steel allows use up to 1500 °C and under corrosive gas conditions such as sampling from industrial smoke stacks.

Each impactor consists of a deep collection dish or chamber surrounding an impaction nozzle. No grease coating is used on the collection surface. Dr. Lundgren noted that his studies are aimed at examining the possibility that collected particles may be reentrained after collection in the chambers. He generated a test aerosol of dry dust (Arizon Road Dust, AC Fine), with a Wright dust feed mechanism.

A conventional impactor with coated stages was used to separately study the aerosol and to measure the size distribution. The results showed little or no evidence of reentrainment, with good agreement between the two impactors with respect to the size distribution of the source dust. A typical test run resulted in the collection of 2.75 g (85.1%) on the first stage, 0.244 g (7.6%) on the second stage, 0.213 g (6.6%) on the cyclone, and 0.023 g (0.7%) on the filter.

Aerodynamic particle size analyzers

The last paper of the first session, "Aerodynamic Size Measurement by Laser-Doppler Velocimetry," by J. C. Wilson and Benjamin Y. H. Liu was given by Dr. Wilson, a research associate at the University of Minnesota's Department of Mechanical Engineering. By accelerating particles in a flowing aerosol stream, using a converging nozzle, and measuring the particle velocities at the nozzle outlet, the aerodynamic sizes of the airborne particles were measured.

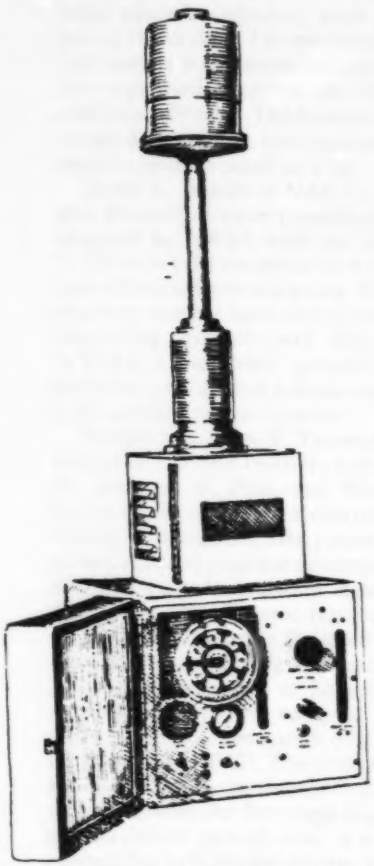
Wilson reviewed the differential equations of motion of aerosol particles with respect to the carrier gas and showed by dimensionless analysis, based upon physical and dynamical similarity, the relationships between observed particle velocity under acceleration conditions and the Stokes number for a given particle, nozzle diameter, and flow rate.

A direct relationship exists between a particle's aerodynamic size and the observed particle velocity exiting the acceleration nozzle if the particle's Reynolds number is less than 0.5, so that the particle's motion is in the Stokes regime. However, for larger particles, the Reynolds number may be higher than 0.5, and the density of a particle of given aerodynamic size will also affect the resultant velocity during acceleration.

The velocities of particles exiting a nozzle were measured with a laser-Doppler velocimeter in which the particle velocity is related to the Doppler frequency, time-fringe spacing. Small particles tend to follow the accelerating gas streams more readily and reach higher velocities than larger particles that have greater inertia.

Dr. Wilson described experiments performed to characterize the laser-Doppler system using monodisperse aerosols of oleic acid (density, 0.886 g/cm^3) generated with an ultrasonic vibrating stream droplet generator, and polystyrene latex particles (density, 1.05 g/cm^3) with sizes from 0.5 μm to 11.3 μm. He proposed nozzle configuration and flow rates for measurement of aerodynamic diameters from 0.1 μm to 10 μm, but noted that the technique is limited to one order of magnitude at a given flow rate.

Wilson discussed the agreement of experimental data and theoretical predictions of particle velocity with respect to aerodynamic size. For larger particles with Reynolds numbers larger than about 0.5, particle acceleration is not controlled by gas viscosity alone, and the velocity of a particle exiting the nozzle is a function of both aerodynamic size and particle density. However, the resulting differences are small (rarely more than 10%), and this is not a major shortcoming considering the many advan-



Particle sizing. *Dichotomous samplers collect inhalable particulate matter.*

tages of this technique. Hence, the laser-Doppler velocimeter provides an automatic, nondestructive, and accurate measurement of aerosol aerodynamic size.

Sample collection and dilution

The problem of extracting a particle sample from the stack environment, diluting it, and/or cooling it to the ambient temperature for measurement is a well-known and often difficult problem. Several papers addressed this problem. A paper by John C. Elder, L. Littlefield, and M. Tillery of the Los Alamos Scientific Laboratory dealt with the development of an improved instrument for measuring the particle concentration in stack gases.

The important features of the prototype sampler are:

- a high sampling rate (56 L/min), continuous monitoring of the operating variables
- calculations of the sampling rate and volume in SI units
- a virtual impactor with a cut point of 3-μm diameter for separating and collecting fine and coarse particles on glass fiber filters
- a variable area nozzle to allow isokinetic sampling at a constant flow rate.

Two methods of measuring the sample flow are provided in the prototype system. One is a hot-wire mass flowmeter and the other is a turbine meter. The flow rate is set using needle valves; measurement is made after the gas is cooled and dried.

A special psychrometer was developed to measure the amount of water vapor in the sample gas. Thermistors are employed to measure the wet and dry bulb temperatures for dew points up to 100 °C. The resulting calculations of moisture content are reported to be accurate within 5%. The measurements of pressure required to operate the system are made using commercial, variable-reluctance, differential-pressure transducers.

The temperatures at various points in the system are measured using thermistors or platinum resistance thermometers. A microprocessor is used to acquire the operating data and perform calculations. A digital display of the operating parameters and sampled volume is available on demand.

The variable-area nozzle and virtual impactor are parts of a single unit. Both have rectangular cross-sections, and one side of the nozzle is adjustable through a screw mechanism from outside the stack. The nozzle position is determined from the resistance of a calibrated potentiometer that is also located outside the stack.

Preliminary laboratory studies indicate that the maximum collection efficiency of the virtual impactor is about 77% for large particles and that wall losses are high; thus, that part of the system will require further development. Overall, the size and weight of the new stack sampler are about the same as a conventional EPA Method 5 train.

Kenneth T. Knapp of EPA described the results of experiments to determine particle losses in buttonhook nozzles. Frequently, these nozzles are used to allow in-stack sampling through small diameter ports, but recent emphasis on measuring the distribution of larger particles (diameters up to 15 μm) makes their application questionable.

In graphing the measured particle retention or collection efficiency versus particle diameter for buttonhook nozzles $\frac{1}{4}$, $\frac{3}{16}$, and $\frac{5}{16}$ inches in diameter, a more or less bell-shaped curve resulted. Generally, for flow rates typical of those used with in-stack impactors (0.5–1.0 ft^3/min), the maximum retention was 50–90% at particle diameters of 9–14 μm.

Tests were also made to measure the dependence of particle retention upon sampling time. Using redispersed fly ash in a wind tunnel, measurements of particle retention in a $\frac{1}{4}$-in. diameter buttonhook nozzle were made at a sampling rate of 0.5 ft^3/min. For sampling periods of 5, 10, 20, and 30 minutes, the retention was found to be quite large, 32–44%, and independent of the sampling time.

It was concluded from these experiments that buttonhook or bent nozzles are definitely unsuited for use with sampling devices measuring the size distribution of inhalable particles, and that they may distort measured size distributions for particles as small as 5 μm in diameter.

Robert J. Heinsohn and J. Davis of Pennsylvania State University and Dr. Knapp reported on a source sampling system that incorporates a dilution scheme to simulate the interaction between emissions from a stack and ambient air. Suitable sensors and transducers are used, and signals are processed electronically to calculate and display operating parameters and sampled volume.

The heart of the system is a dilution ejector pump. A sample volume of 0.5–1.5 ft^3/min is extracted from the stack and diluted by a factor of 10–15 with dry, filtered air. The diluted stream generally is sampled on a filter, but some comparison tests were made with in-stack cascade impactors to determine the effects of dilution and cooling on the particle size distribution. Another interesting feature is a valving and flow system that allows the operator to pass clean air through the metering orifice to clean or calibrate it without removing the system from the sampling port.

Tests were made at three sources with the new system, a conventional EPA Method 5 train, and an in-stack impactor. Results from the field evaluation indicate that the new system generally yields a higher mass than the front half of a conventional Method 5 train. The size distribution of the diluted aerosol is also different, and for some combustion sources, a submicron mode was observed that was not present in the stack.

Real-time monitors/data reduction

Several instruments described at the symposium are capable of measuring particles in real time. Dr. Raymond L. Chaun of Brunswick Corp. described the quartz-crystal microbalance (QCM) cascade impactor that he developed for NASA to obtain in situ particle size distributions, elemental

composition, and morphology of aerosol particles. This unit is a multistage cascade impactor, each stage having two crystals. On one crystal, the dust sample is deposited by impaction onto a greased substrate; the other is used as a reference. The measurement circuit developed for the impactor can detect a mass as small as 1 ng.

David C. Woods of NASA's Langley Research Center presented data obtained by NASA with the QCM. NASA has used the impactor to measure effluents from volcanoes. The instrument also has been used to provide supporting ground-truth data for NASA's stratospheric aerosol measurement and aerosol and gas experiment satellite measurements.

A paper by Clinton E. Tatsch of the Research Triangle Institute and Jean W. Johnson, B. Pyle, and Wallace Smith of the Southern Research Institute (Birmingham, Ala.) described a computerized program developed by SRI for cascade impactor data reduction for EPA. Johnson reported on an extrapolating curve fit based on a first-order osculating polynomial which was developed to be used in conjunction with the computer impactor data reduction system (CIDRS, EPA 600 /7-78-042). The procedure, which accurately predicts size distributions between the first stage D_{50} and the maximum particle size, was developed due to increased interest in the health effects of cumulative particulate concentrations for particles less than 15 μm.

Tatsch discussed the approach used to convert the CIDRS program written for use on a PDP-15/76 computer to allow use on a IBM 370/168 computer. The conversion was made with the intention of producing a system of programs of general utility to the impactor users. The major program modifications were made in the software-hardware plotter interface (i.e., card reader, printer, plotter, and disc storage).

The revised coding was developed to minimize difficulties in working with other systems. Spencer commented that the CIDRS program had been converted by EPRI for use on the Data General minicomputer system at EPRI's Arapahoe Test Facility. The program had significantly reduced the time to reduce impactor data. Discussions during and after the session indicated that many of the attendees believe that computers can be further used to improve cascade impactor data reduction through development of programs to include the effects of nonideal operations.

Heinz Fissan of the Gesamthochschule Duisburg, West Germany, followed up on this theme and discussed the results he obtained with data reduction programs that include nonideal instrument behavior. Dr. Fissan, along with C. Helsper, conducted calibration experiments with monodisperse aerosols to describe nonideal instrument behavior for an electrical aerosol analyzer (EAA), an optical particle counter, and an Andersen cascade impactor.

Using knowledge of the instrument characteristics obtained from the calibration measurements, they simulated instrument output for given size distributions and then conducted simulation tests. They predicted the output of the instrument based on an assumed size distribution, compared the predicted output with measured output, and adjusted parameters until the assumed size distribution produced an output equivalent to that of the instrument when measuring an unknown size distribution. Thus, the unknown size distribution was determined.

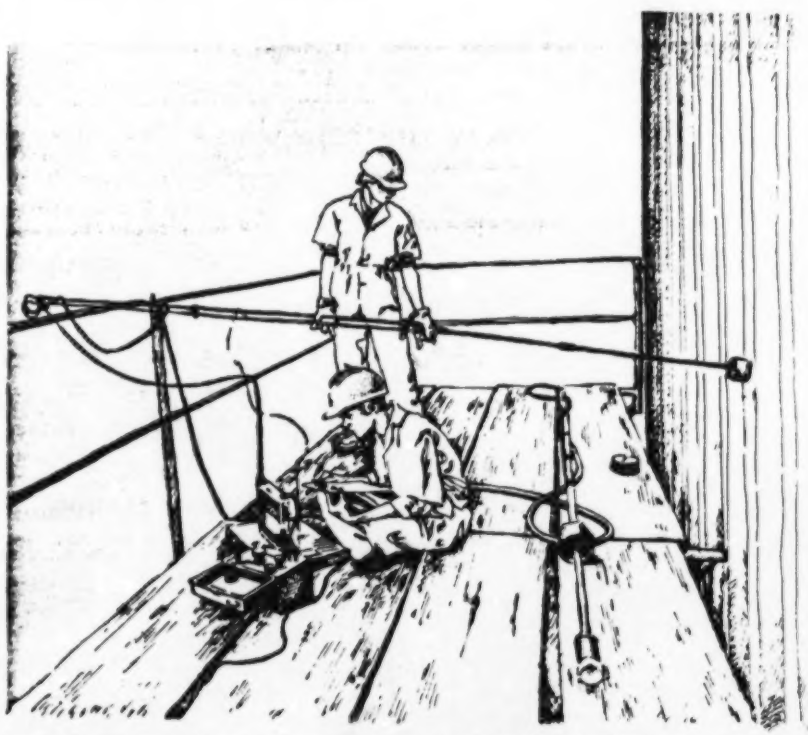
The distribution parameters were adjusted by means of a simplex minimization procedure which uses a modified chi-square function as a measure of goodness of fit between the simulated and measured outputs. When estimated starting parameters were in a range of approximately ±30% of the actual values, size distributions were recovered with a success rate of 94%. Fissan believed the procedure's main limitation was lack of knowledge about instrument behavior for real aerosols compared to those used in the calibration experiments.

Joseph D. McCain from Southern Research Institute also dealt with the nonideal behavior of a cascade impactor. Comparisons of recovered size distributions predicted by means of a computer model of cascade impactor operations for four cases were given. Four modes of operation were compared:

- ideal behavior with a perfectly sharp cutoff
- a model based on actual stage collection efficiencies determined through calibrations with no particle bounce
- actual stage collection efficiencies with a normal amount of particle bounce
- actual stage collection efficiencies with an extreme amount of particle bounce.

The results of McCain's study revealed that:

- Systematic errors in measured mass median diameters and geometric standard deviations occur when aerosols having log-normal size distribution are sampled.
- Larger errors occur when sampling aerosols with small (<1 μm)



In-stack sampling. *Taking a representative particle sample from the hostile environment of stacks is a complicated task*

mass median diameters compared to those having larger (10–20 μm) mass median diameters.

• Particle bounce has very little effect on the weights of particulate matter caught on the various impactor stages, but has a pronounced effect on the weight of the material caught on backup filters.

When sampling dry, hard particles, the last effect results in substantial overestimates of the concentration of very fine particles.

Prototype instruments

Kazuo Tsurubayashi of the Nihon Kagaku Kogyo Co., Japan, described an automatic piezoelectric microbalance for concentration measurements on ambient aerosols. The monitor has a high sensitivity for mass concentration and can be operated unattended for weeks at a time. The instrument was designed with an automatic cleaning cycle which washes the collection substrate every 30 minutes.

Data comparing the operation of the unit with a low-volume filter sampling system showed a very good correlation. The only apparent problem was due to moisture absorption on the substrate with high dust loadings, but this effect was minimized by short cleaning cycles. The instrument appears very promising for unattended ambient sampling.

A novel prototype instrument that employs an automatic isokinetic sampling probe and a unique sensor to measure particulate mass in real time was described by J. C. F. Wang of Sandia Laboratories (Livermore, Calif.) and Harvey Patashnick of Rupprecht and Patashnick Co. (Englewood, Colo.). The automatic isokinetic sampling probe is of the null balance type, which equalizes static pressure within the sampling nozzle with the local free-stream static pressure.

The particulate mass is detected by a patented Tapered Element Oscillating Microbalance (TEOM). This detector employs a filter which sits atop a hollow tapered tube constructed of a material with high mechanical quality factor. Particle-laden gas is drawn through the filter and the hollow tapered tube via a vacuum pump.

The tapered tube is set into oscillation between two electrostatically charged plates. As the deposit builds up, the oscillating frequency of the filter/tapered tube combination will change. This change is measured and is used to compute the mass of the deposited particles. The TEOM apparatus has a major advantage over a quartz-crystal microbalance (which also measures particulate mass by a frequency shift) in that it has a much larger capacity for deposited particles. The range of this detector is limited only by the capacity of the filter.

This prototype instrument has been evaluated in a room-temperature wind tunnel, and results indicate good agreement between the particle feed rate to the wind tunnel with the particulate mass measured by the instrument.

Gilmore Sem of TSI, Inc. (St. Paul, Minn.) described a commercially available instrument which sizes particles in the 0.005–0.2-μm range. This instrument combines a diffusion battery with an automatic valve and a condensation nucleus counter to automatically measure a size distribution in approximately four minutes. The system offers a major advantage in that it can operate over a wide range of particle concentrations ($<1 -> 10^6$/cm^3) without a dilution system.

The diffusion battery is a multiple screen type consisting of 55 4-cm-diameter stainless steel screens mounted to sequentially sample each sizing interval of the battery automatically. Losses in the valving system have been experimentally determined and are taken into account in the calculated size distribution. A continuous flow, condensation nucleus counter is used to detect the particles from each sizing interval from the diffusion battery.

This condensation nucleus counter employs two modes to handle the wide concentration range of the instrument. Concentrations below 1000/cm^3 are measured by counting individual particles as they pass through the sensing zone of a forward-scattering optical particle detector. For concentrations greater than 1000/cm^3, the total forward-scattered light is measured for all particles in the sensing zone.

This measurement system was experimentally compared with an electrical aerosol analyzer also manufactured by TSI, Inc., on several laboratory aerosols. Good agreement was achieved between the techniques in the range from 0.01–0.2 μm. The current system cannot effectively measure particles below 0.01 μm because of particle losses in the system.

A commercially available instrument developed with EPA support was described by Daniel Magnus of KLD Associates, Inc. (Huntington Station, N.Y.). This instrument uses a hot wire technique to provide in situ sizing of liquid droplets in the 1–66-μm range. It consists of two components, a probe and an electronics box. The probe is made from platinum wire 5 μm in diameter with an active length of 1 mm. Initially, the wire is heated; then, when a droplet impacts onto the wire, local cooling of the wire causes a voltage drop which is related to the size of the droplet. The signal is analyzed and classified into one of 14 intervals.

Laboratory comparisons with a cascade impactor and a calibrated spray nozzle showed good general agreement, although there was significant scatter in the impactor data.

The instrument has been used to evaluate the performance on demisters on limestone scrubbers for desulfurization of flue gas from electric power plants. The instrument measured the average drop size and the mass and number concentrations. Results showed that two demisters in series reduced the mist concentration by about half with no appreciable change in drop size. The equipment has also been used to measure entrained droplets in quenching towers and oil mist in a manufacturing process.

Inhalable particles

The session on inhalable particles began with a paper by Dennis Drehmel of EPA entitled "Considerations for Establishing a Standard for Inhaled Particles." He reviewed the sequence of considerations preceding the establishment of an inhalable particle standard. The considerations began with results from studies of health effects.

It was pointed out that in a normal individual, the largest size of particles that can be inhaled into the lungs through the nose is 10 μm. However, when mouth breathing is considered, particles as large as 15 μm can be inhaled. There is also considerable variation among individuals, particularly smokers and nonsmokers.

Since EPA must consider all segments of the population, particularly those who are more vulnerable to environmental pollution, a new definition for inhalable particles was chosen which differs from the conventional definition of "respirable particles" used in industrial hygiene. These results, combined with information on the nature of atmospheric particles, have led to the selection of 15 μm as an upper limit for inhaled particles and 2.5 μm as an intermediate size for possible future standards development. EPA plans to publish the new proposed inhalable particle standards in May 1980, and promulgate the new standards by the end of 1980.

To implement inhalable particle standards, the contribution of sources to inhalable particles in the atmo-

sphere must be determined. Information is now being gathered on emission source characteristics related to inhalable particles. Where source emissions are known to be completely less than 15 μm, emission factors can be readily developed by the use of existing information. Where source emissions contain particles larger than 15 μm, new emission factors must be established, empirically or by data analysis, using known size-distribution characteristics of the emission sources.

In cases where new emission factors must be established, the current and future availability of measurement technology must also be considered. Both stack and fugitive sources with or without condensibles must be tested. Finally, measurement procedures must be standardized through the establishment of federal reference methods.

Wallace Smith of Southern Research Institute reviewed the development of size-selective samplers at SRI for sampling inhalable particles. The paper, entitled "Some Aerodynamic Methods for Sampling Inhalable Particulates," was jointly authored by Wallace Smith, Kenneth M. Cushing and Rufus Ray Wilson, Jr., of SRI and D. Bruce Harris of EPA. Among the size-selective samplers developed was a horizontal elutriator intended for sampling fugitive and atmospheric aerosols.

The prototype horizontal elutriator performed in accordance with theory. It was pointed out that the major advantages of the horizontal elutriator are that it can be designed theoretically and that particle bounce and reentrainment, problems which plague the impactors, are generally absent.

In addition to the horizontal elutriator, SRI has developed a cyclone precollector which is intended for in-stack use either with cascade impactors or with filters and a series-cyclone apparatus, which is also intended for in-stack use. Each system has been calibrated under typical test conditions and performs within the specified range for samplers for inhalable particles. The equipment will be used to determine emission factors for inhalable particles from stationary sources.

The paper, "Deposition of Inhaled Particles and Possible Sampling Methods," by Vittorio Prodi and C. Melandri was presented by Dr. Prodi. Prodi, a well-known aerosol physicist with the Laboratorio Fisica Sanitaria in Bologna, Italy, provided a general review of the mechanics of particle inhalation and the available data on particle deposition in the human respiratory system. He pointed out in particular the sensitivity of particle deposition to the main aerosol properties and to physiological and possible pathological factors, and the considerable variability of deposition among individuals.

Dr. Prodi then reported on two methods which are under development in his laboratory for inhalation toxicology work. One measures the size distribution of airborne particles by use of a recently proposed aerosol spectrometer. The spectrometer consists of a rectangular nozzle pointed near one end of a filter. Particles leaving the nozzle travel toward the filter; the largest particles collect on that portion of the filter closest to the nozzle, while the smallest particles collect at points farthest away from the nozzle. The size-separated particles collected on the filter can then be subjected to further physical or chemical analysis. A second method involves separating the particles into different size fractions corresponding to different regional depositions in the lung.

The final paper of the session, "Ambient Aerosol Sampling Inlets and Inhalable Particles" by B. Y. H. Liu and D. Y. H. Pui of the University of Minnesota, was presented by Liu. He reviewed the various approaches to inlet designs, pointing out that almost all the available inlets perform rather poorly in terms of their sampling efficiency for large particles, particularly at high ambient-wind speeds.

Liu said that poor performance can be attributed to particle loss on external and internal surfaces of the inlet. Loss of particles on external surfaces generally results from particle impaction due to wind, whereas loss on internal surfaces can be attributed to impaction, sedimentation, and turbulent deposition. An ideal inlet should transmit a representative aerosol sample from the ambient atmosphere to the sample collection zone within the instrument.

Dr. Liu then proceeded to describe a new aerosol inlet developed at the University of Minnesota and the considerations entering into its design. The inlet was intended for the virtual dichotomous sampler and for a sampling flow rate of 1 m^3/h or 16.7 L/min. The inlet has a funnel-shaped entrance region followed by a cup-shaped impactor to remove the coarse, noninhalable particles above 15 μm.

Particle impaction on external surfaces is prevented in this inlet by a horizontal flange on the top of the funnel. The flange keeps the streamlines straight prior to their entry into the funnel. Internal loss is minimized by using a funnel of a suitable size. Wind tunnel tests showed that the inlet's performance is quite independent of wind speed up to the maximum wind speed used, viz. 9 km/h. Further wind tunnel tests at higher wind speeds will be performed.

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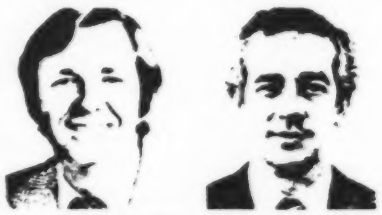

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